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DEPARTMENT OF THE INTERIOR

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JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

PROGRESS REPORT 4 ON INVESTIGATION OF DETACHABLE ROCK-DRILL BITS

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BY

McHENRY MOSIER

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PROGRESS REPORT 4 ON INVESTIGATION OF DETACHABLE ROCK-DRILL BITS[1]

By McHenry Mosier[2]

INTRODUCTION

This is the fourth progress report in the series on the use of detachable rock-drill bits in the metal mines of the United States. It contains comparative statistics and costs on drilling at eight mines not reviewed in previous reports[3], comparison of the use of detachable bits at small mines and large mines, a discussion on the life of drill rods, and general conclusions derived from an analysis of the rock-drilling practice at all the mines investigated on this survey. This paper completes the descriptions of operating practice in rock drilling at individual mines. Data on drilling practices at 28 mines are given in appendices I and II and drilling costs are shown in appendix III.

Research in the fundamentals of rock drilling, including the use of detachable bits, has been undertaken by the Bureau of Mines in its testing adit at Mount Weather, Va. Reports on the progress of this investigation will be issued when results warrant their publication.

ACKNOWLEDGMENTS

As in the previous reports of this series, costs and other data at the individual mines investigated were developed by the operators, except as noted in the text. The assistance and cooperation of the officials and staff members at the mines visited are gratefully acknowledged.

GENERAL CONCLUSIONS DERIVED FROM ANALYSIS OF DATA DEVELOPED BY 28 METAL MINES

Rock-drilling practice, including the use of detachable bits, is an individual problem at each particular mine. Since the process of drilling comprises many subdivisions, each with wide variations from one property and one district to another, it is difficult to establish a fixed universal

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2/ Supervising engineer, metal mining research section, Mining Division, U. S. Bureau of Mines.

3/ Mosier, McHenry, Progress Reports on Investigation of the Use of Detachable Rock Drill Bits: Information Circulars 6877, 6911 and 6936 Bureau of Mines, 1936 and 1937.

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standard for this work. The true basis of comparison between the detachable bit and the conventional bit is the total cost per foot of hole drilled at the mine under consideration.

The success or failure of detachable bits at a given property depends not only on the comparative service of the bits but also upon the quality of the fabricated rods or shanks to which the bits are attached. Since in general, at this date, the development of rods has not kept pace with improvement in the manufacture of detachable bits, the service of a rod at present hinges principally upon its treatment during fabrication in the conversion shop. Thus, improper shop methods in making up rods might cause an adverse decision on the adoption of detachable bits even though their drilling performance were favorable in all other ways.

Although it is difficult to avoid personal prejudice in research and to form unbiased conclusions, yet an honest desire to determine the facts, with due consideration of all the items affecting the total cost of drilling, will do much to eliminate conflicting information concerning the use of detachable bits.

An imperical index for the use of detachable bits in metal mines has been derived from an analysis of drilling practice at those metal mines throughout the United States where comparative data were known to be available. This does not apply to small contracts for rock excavation but pertains to routine metal-mining operations. The index is based on the life of a detachable bit in terms of feet drilled from its initial use until its final discard. In other words, the life is the sum of the distances drilled on all its uses, including those after each reconditioning; it is the total feet drilled per bit purchased. Although the life of a detachable bit is not a simple function of any single quality of the rock drilled, nor of any one characteristic of drilling equipment, yet its principal factor is the abrasiveness of the rock drilled.

Under present conditions at the metal mines included in this survey, if the life of a detachable bit is in excess of 10 feet, its use is almost certain to prove more advantageous than that of the conventional bit on regular steel, provided the diameter of the drill hole in normal use lies within the range of detachable bits. If the life is less than 4 feet, there is little prospect that detachable bits will prove economical.

This 4-foot limit is one of the curious things discovered from comparison of data from all the mines studies. Although empirical, it may be that under these conditions the depreciation charge on detachable bits exceeds transportation and forging costs for conventional bits. If the life lies in the zone between 4 and 10 feet, usually there must be some special condition to warrant the adoption of detachable bits. If this special condition does not occur throughout the entire mine, the use of detachable bits may be limited to certain sections or to specific operations where the favorable circumstances do apply.

DETAILED ROCK-DRILLING DATA AND COSTS AT INDIVIDUAL MINES

Comparison of rock-drilling practice with conventional and detachable bits at eight individual metal mines is shown below. Where costs and data on drilling performance were available, they are also included for each mine investigated.

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WESTERN MINE NO. 1

CONCLUSIONS

At this mine detachable bits are becoming the standard for all drilling. The only conventional bits now in use are those used with hand-rotated stopers, which are being replaced gradually by self-rotated machines. A marked decrease is shown in the total cost per foot drilled with detachable bits. The use of detachable bits has reduced the amount of time lost by miners in transporting drill steel and has increased the time available for drilling at the face. Detachable bits have increased the drilling speed.

ROCKS DRILLED

The rocks drilled at this mine are metamorphosed sediments into which have been intruded diabase and porphyry. All of these rocks, including the ore areas, have been considerably silicified. The ground, although quite variable in hardness, is considered to be good drilling.

OPERATING PRACTICE

The machine drills in use are 2-1/4-inch and 2-5/8-inch jackhammers, 2-1/4-inch and 2-3/4-inch hand-rotated stopers, 2-5/8-inch and 3-inch automatic rotated stopers, and 3-1/2-inch drifters. A few of the drifters are equipped with automatic feed. There is one operator per drill. Air pressure at the compressor is 90 to 95 pounds per square inch and at the drill it is 80 pounds minimum. The average depth of holes is 5 feet in development headings and 12 feet in the undercutting in stopes. Jackhammers have a penetration of about 6 inches per minute, while 3-1/2 inch drifters have 12 inches and 4-inch drifters 15 inches per minute. The effective drilling time is 4 hours per machine-shift.

REGULAR STEEL WITH CONVENTIONAL BITS

Conventional bits are the standard cross type with 90° between cutting faces and with double clearance tapers of 5° and 14°. The carbon content of the steel is 0.85 percent.

The sharpening shop, which is at the collar of the shaft, has the following equipment: 3 machine sharpeners (2 are now spares), 3 punches (2 are now spares), 4 single-opening oil furnaces that use high-pressure air, 1 pyrometer on furnace for quenching heat, 2 forges and anvils, 1 water quenching tank, 1 oil quenching tank (water-jacketed by being placed inside a larger tank), and 1 air hammer.

The incoming dull steel is sorted by lengths and placed in suitable racks. At present, 50 pieces of steel with conventional bits are sharpened per day. The routine for forging and hardening, which follows accepted standards, includes the treatment of the hot bits with powdered cyanide. A 5-pound can of cyanide, costing $2.25, will treat 2000 bits. The life of a bit is thus increased approximately 30 percent. Before detachable bits were introduced, one operator and his helper sharpened 425 pieces of steel per shift.

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Reconditioning conventional steel at this mine follows a 6-day cycle. In other words, it requires 6 days for a given piece of steel, after leaving the sharpening shop, to be transported to the underground magazine and to the working face, and then, after it is used, to be returned to the magazine, transported to the sharpening shop, and resharpened. In this 6-day cycle, the effective drilling time for an individual bit is approximately 2 minutes.

DETACHABLE BITS

The only new equipment added to the shop to recondition detachable bits was one bit-grinding machine.

Three sections of steel are used in making up rods, as follows: 1-1/4-inch hollow round for drifters; 7/8-inch hollow quarter octagon for stopers; and 7/8-inch hollow hexagon for jackhammers.

The detachable bits are mostly the four-point or standard cross-bit pattern, although there are a few six-point or rose-bit pattern. While it is thought that the latter type has some advantages, no definite conclusions have been reached regarding the standard for the mine. All bits have a central water hole.

All new bits purchased for 1-1/4-inch steel are 2-1/8 inches in diameter, while those for 7/8-inch steel are 2 inches in diameter. Bits are ground to standard 1/8-inch gage changes. With 1-1/4-inch steel the finisher has a 1-5/8-inch gage, and with 7/8-inch steel it has a 1-1/2-inch gage.

All dull bits returned from the mine are annealed before each regrinding. This is done by placing them in a furnace heated to about 1,800° F. After the burner is turned off, the bits are left overnight to cool with the furnace. On the following morning these annealed bits are ready for grinding. One operator can grind 150 bits per shift.

The average life of a forming wheel is about 1,400 bits, while that of a gaging wheel is 2,400 bits. The bits sharpened were mixed sizes and gages, about 75 percent being for 7/8-inch rods and 25 percent for 1-1/4-inch rods. The bevel angle on the forming wheel for cross bits is 60° and for six-point bits is 50°. The life of the grinding wheels and the speed of cutting are increased by the use of a soluble cutting oil diluted with distilled water in the ratio of 1 part of oil to 60 parts of water. As an additional protection to the operators beyond that provided by wet grinding, the use of respirators while grinding is compulsory.

The bits are hardened after each regrind. They are screwed onto 7/8-inch drill-steel holders 22 to 25 inches long. After being heated in an oil furnace to about 1,500° F. they are plunged into a rising current of cold water with a submergence of 1/2 inch, or to the base of the wing. The quenching trough and the rack for supporting the bits and their holders are shown in figure 1. About 75 bits are hardened per hour by one operator, whose wage is $0.50½ per hour.

Bits average four regrinds, or five uses. With an average penetration of 8.92 feet, the life of the bit is 44.6 feet.

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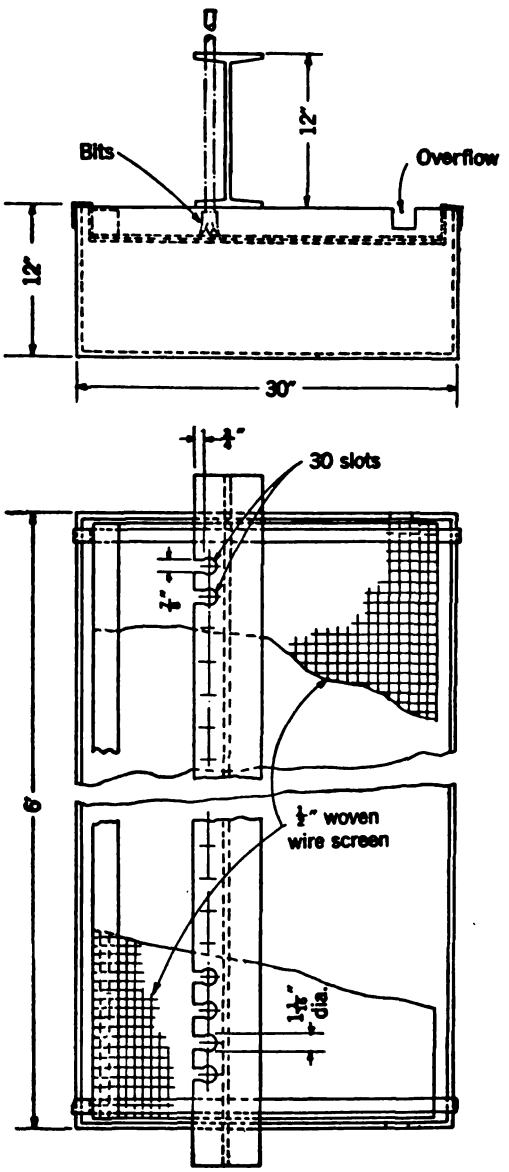

Figure 1 -Quenching trough with rack for supporting bits.

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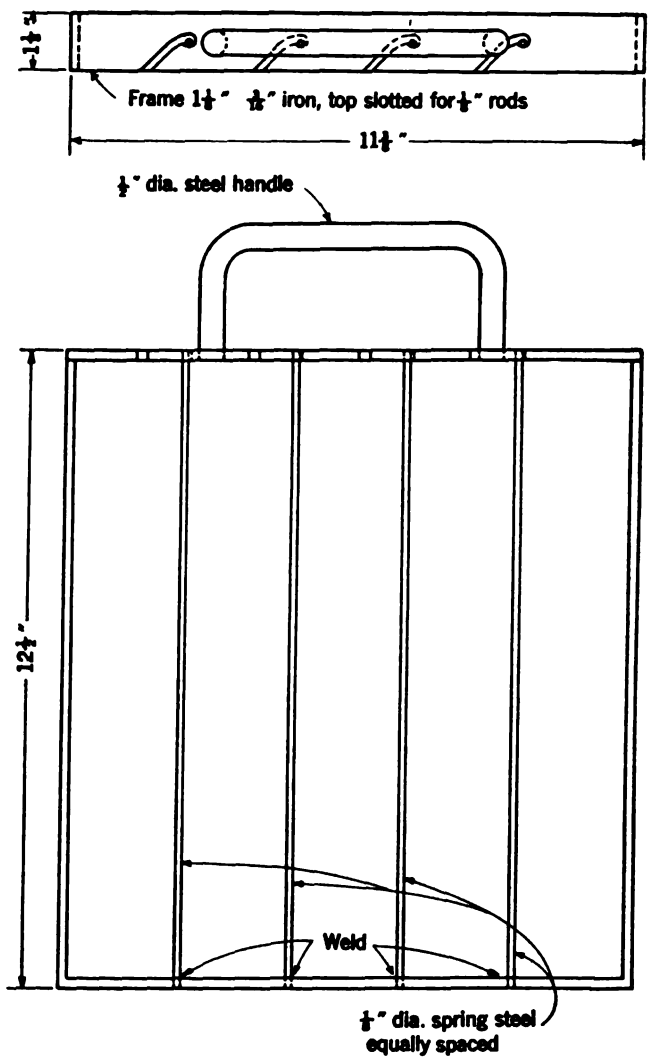

Figure 2 -Delachable bit carrier.

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Two bit-carriers of the type illustrated in figure 2 are provided for each miner. These carriers have a capacity of 32 bits for use with 7/8-inch rods, or 20 bits for use with 1-1/4-inch rods. The miner receives sharp bits at an underground tool magazine, which is centrally located, and returns all his bits to the same place. Sharp bits are segregated by sizes and sacked for transportation from the surface shop to the underground magazines. Dull bits are returned from the magazines to the surface in the same manner.

Rods have been fabricated from an old stock of unused drill steel with 0.85 percent carbon content. They are cut into lengths having differentials as follows: rods for drifters, 28 inches; for jackhammers, 24 inches; and for stopers, 18 inches.

The thread end of 1-1/4-inch rods is given a forging heat of 1,800° F. through a distance not exceeding 3 inches preparatory to upsetting. The rod is then normalized by heating to 1,600° F. and cooling in the open atmosphere. Next, threads are rough cut on a lathe at the mine machine shop. The threads are then finished with hand dies. One machinist can thread 5 rods per hour, or 40 rods per shift. The rod is again normalized by heating it slowly to 1,600° F. and maintaining it at this temperature for 1 hour, then cooling in a dry place with no draft. The thread end of the rod is slowly brought to 1,540° F., as indicated by a pyrometer, and held at this heat for 1 hour. There must be at least a 2-inch overlap on the forging heat. The thread end is quenched in oil until black, when it is withdrawn and cooled in the open atmosphere.

The shank end of the 1-1/4-inch rod is heated to 1,800° F. for forging, normalized by reheating to 1,600° F., and cooled in the open atmosphere. In the event that the hole in the steel is undersize, the rod is reheated, punched, and forged to size. The rod is again normalized by heating it to 1,600° F. and cooling it in the open atmosphere. The end is then heated through a length of 3/4 inch to 1,450° F. and quenched in water to a depth of 1/2 inch. When the color above the water line has disappeared from view, the steel is withdrawn from the water and polished with emery cloth fastened on a wooden stick. After this buffing, when the dark purple color reaches the end of the steel, it is quenched in oil until cold. The steel rod rests on a screen rack, 2-1/2 inches from the bottom of the quenching tank. Each shank is file-tested before use.

The thread end of the 7/8-inch quarter-octagon steel is heated throughout a distance of 1-1/2 inches from the end of the rod at 1,800° F. for upsetting. Two heats usually are required for this work. Any surface irregularities are removed by grinding. Normalizing is accomplished by heating to 1,600° F. and cooling in the open atmosphere. After the threads are cut, the rod is again normalized. An overlapping quenching heat is given at 1,540° F.

The shanks on the 7/8-inch quarter-octagon steel are plain and are not forged. After normalizing at 1,600° F., they are hardened in the same manner as the shanks on the 1-1/4-inch rods.

For the 7/8-inch hexagon steel, a similar treatment is given, except that a collar is forged on the shank.

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Each miner is furnished one set of rods. These rods may be exchanged at an underground tool house whenever replacement becomes necessary.

An experienced miner facilitates the removal of the bit from the rod by keeping the compressed air on the machine for a moment after he starts extracting the steel from the hole and by unscrewing the bit immediately after removing the drill steel from the machine.

The loss of detachable bits is approximately 1-1/2 percent of the number issued. No especial trouble has been experienced with the rock crushers at the head of the mill because there is an occasional bit in the feed.

Based on a record of the circulation of drill steel over a 5-month period, the service ratio of regular drill steel to drill rods for detachable bits is 1 : 57. This means that in a given time the number of uses for a rod carrying detachable bits is 57 times greater than that for a piece of regular drill steel. Thus, it is to be noted that more than a year's normal service for a piece of regular steel is crowded into one week for a rod with detachable bits. The actual number of rods in service, including spares and other reserves, is 11.5 percent of the number of pieces of regular drill steel formerly in service for the same number of operating machine drills. The transportation ratio or the weight of detachable bits and rods compared to the weight of regular drill steel required for the same number of operating machine drills is 1 : 24. Or translated into percentage, the use of detachable bits has effected a reduction of 95.85 percent in the total weight of steel transported.

COMPARATIVE PERFORMANCE AND COSTS

The average cost per machine-shift for operating all drills using detachable bits is $3.57. The drills are principally jackhammers, with some stopers and drifters. The cost includes compressed air, which averages 25,000 cubic feet per machine-shift, pipe lines, machine repairs, drill steel, bits, and transportation of rods and bits, but excludes labor in drilling. The drill-shifts used in compiling the above cost total 245,000. Using 116 feet drilled per machine-shift, the total cost exclusive of labor in drilling is $0.031 per foot drilled. The purchase price for new detachable bits amounts to $0.0475 per bit dulled, or $0.0053 per foot drilled.

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[redacted]llowing detailed shop costs for detachable bits were taken from a [redacted]tative month in 1936.

	Number of units	Cost per unit	Cost per bit dulled	Cost per foot drilled
Bits:				
Total Regrinding:	5362	----	$0.0362	----
Total	5362	$0.0350	.0280	----
Labor	5362	.0325		
New wheels	5362	.0025		
Hardening:				
Total	5362	.0103	.0082	----
Labor	5362	.0099		
Supplies	5362	.0004		
Rods:				
Total Forging shanks and thread end:	216		.0177	
Total	216	.2563	.0103	----
Labor	216	.2563		
Supplies	216	—		
Threading	216	.1634	.0066	----
Repairing unplugging and straightening	25	.2132	.0008	----
Total	----	----	.0539	$0.0060

The records for April 1935 showed that the penetration of the detachable bit for each use was 4.44 times that of the cyanide-treated conventional bit on regular drill steel. Details of this test are below:

	Regular steel	Detachable Bits
Number of machine shifts	46	16
Feet drilled	2,589	1,856
Bits dulled	1,288	208
Feet per bit dulled	2.01	8.92
Feet drilled per machine shift	56.28	116.00

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A five-months average for transportation and shop costs for conventional bits on regular drill steel was $0.0466 per foot drilled. Details are below:

	Cost per bit dulled	Cost per foot drilled
Transportation (exclusive of miners' time)- - - -	$0.0420	$0.0209
Shop cost, sharpening (exclusive of new steel or steel replacements) - - - - - - - - - - - - - - -	.0516	.0257
Total transportation and shop - - - - - - - - - - -	.0936	.0466

Although the costs for drilling with conventional and with detachable bits have not been segregated in such a manner as to permit the comparison of all the details, yet there is a marked reduction in the total cost per foot of drilling through the use of detachable bits.

UNITED VERDE EXTENSION MINING COMPANY - JEROME, ARIZ.

CONCLUSIONS

Through a wide range of drilling conditions, the detachable bit has increased the number of feet drilled per bit as well as the drilling speed and has reduced the cost of nipping. The diminished scale of operations and the large stock of regular drill steel has retarded the adoption of detachable bits throughout the entire mine. Complete costs to compare detachable bits with conventional bits are not available at present.

ROCKS DRILLED

The rocks drilled are silicified gossan, diorite, greenstone, schist, and porphyry. A variety of drilling conditions is encountered, from occasional sticky ground through irregular seamy areas to hard and abrasive rock.

OPERATING PRACTICE

The cylinder diameters of the machine drills in service are as follows: Drifters, 3-1/4 inches; jackhammers, 2-1/4 inches, hand-rotated stopers, 2-3/4 inches; and automatic rotated stopers, 2-11/16 inches. Anvil blocks are used in stopers only. There is one operator per machine. The air pressure is 100 pounds per square inch at the compressor and from 80 to 90 pounds at the drill.

Three sections of drill steel are in use, viz., 1-1/8-inch hollow round with lugged shanks for drifters, 7/8-inch hollow quarter-octagon with plain shanks for stopers, and 7/8-inch hollow hexagon with collared shanks for jackhammers. The bits are the 4-point type with an angle of 90° between cutting faces and with double clearance tapers of 5° and 14°. The gage change is 1/8 inch on a drill run of 18 to 24 inches. Most bits have a central hole, but a few bits for use in sticky ground have a side hole.

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The bits are forged at an estimated 1,800° F. and are reheated to 1,500° F. for hardening. They are quenched in water.

The shanks are subjected to a forging heat of 1,800° F. and are cooled in the open air. The ends are then reheated to 1,600° F. through a distance of 2 inches and after treating with a hardening compound are quenched in oil.

CONVENTIONAL BITS

With conventional bits on regular steel approximately 1.5 feet are drilled per bit dulled. The feet drilled per machine shift in drifts and crosscuts varies from 60 to 70, depending upon the ground, while in stopes it is about 50. The drill holes average 5.5 feet in depth.

The sharpening shop is on the surface near the collar of the supply shaft. Its equipment comprises the following: 2 oil-burning furnaces for forging heat, 1 oil-burning furnace for hardening heat, 2 machine sharpeners, 2 punches, 2 portable steel rack supports, 2 sliding steel racks at furnaces, 1 double emery wheel, 1 air hammer, 2 anvils, 1 forge, 2 quenching tanks, and various small tools. High-pressure air from the mine compressed-air mains is used in the furnaces. The steel drills are loaded on special cars, which run on rails through one portion of the shop and on steel turnsheets through the remainder. The dull steel from the mine is placed in bins along the walls of the shop. The sharp steel is loaded directly from the quenching trough into the special steel cars. These are constructed with compartments formed by metal dividers so that the drill steel stands vertically in the car. Underground, the nippers push the steel cars from the shaft stations to distributing points, whence the miners carry the steel to the working faces. The nippers collect the dull steel at the face.

With an output of 300 pieces of drill steel per day, two men are required in the shop for unloading, sorting, cleaning, sharpening, hardening, and loading. The total shop cost per bit sharpened, including steel loss, is estimated to be $0.10.

DETACHABLE BITS

Detachable bits are used principally in development through schist and in stopes where the nipping cost is high. Short time studies have indicated a greater number of feet drilled per bit and a higher drilling speed than with regular drill steel. As yet, no actual operating data are available for complete detailed comparisons. On the present diminished scale of operations, there is a comparatively large quantity of regular drill steel on hand which has tended to retard the adoption of detachable bits throughout the entire mine.

Detachable bits are reground on a home-made machine by the rock-drill repairman in his shop adjoining the collar of the shaft. The bit grinder consists of a double emery wheel with a 12-inch forming wheel and a 10-inch gaging wheel. A guide for the bit holder was developed by cutting a 2-inch pipe in half, longitudinally, through a length of 5 inches, and by welding one of these pieces to a post supported by the tool rest supplied with the original equipment. The trough thus formed was sloped at an angle of 14° from the horizontal and was notched at its lower end to conform to the bevel of the wheel. Two lugs, 1/4 by 1/2 by 1 inch, were welded near the upper end of the pipe to maintain the bit holder in alignment. The bit holder itself was simply a short

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shank of jackhammer steel, onto which the bit was screwed.

The drill steel for use with detachable bits is 7/8-inch hexagon and 7/8-inch quarter-octagon. The bits are 4-point with side hole. There are four regrinds or five uses per bit. About 10 bits are dulled per day. Bits are resharpened at the rate of 15 per hour. One sharpening wheel will grind 1,000 bits. Detachable bits are not reforged nor rehardened at this property. New bits purchased average 50 per month.

In reconditioning rods, the thread end is heated to an estimated 1,800° F. and upset in a machine sharpener. Threads and shoulder are cut in a bolt machine with a special set of dies. After heating to approximately 1,450° F. and sprinkling with a hardening compound, the thread end is quenched in oil until cold. The shank end is given heats for forging and hardening that correspond to those above. The total rod breakage is less than 1 percent.

Bits are exchanged by the miners on the surface at the sharpening shop. The bit carrier is a simple wire loop. There have been no broken bits, and the percentage of bits lost is negligible.

WESTERN MINE NO. 2

CONCLUSIONS

Detachable bits are used exclusively in driving drifts, while conventional bits are used in stoping, raising, and shaft sinking. The large number of hand-rotated stopers in service has prevented the use of detachable bits in stoping and raising. In order to overcome this limitation, an experiment is being conducted for adapting detachable bits to hand-rotated stopers by means of a ratchet in the fronthead, but the results are not yet conclusive.

Because of the distinct separation of the two systems of drilling, operating data are not available for detailed comparisons. Notwithstanding the fact that the shop cost of forging conventional bits on regular drill steel is less than the purchase price of detachable bits plus the cost of regrinding, the advantage in the cost per foot drilled appears to be with the detachable bits because of the large savings in transportation expense and the reduction in the loss of steel.

ROCKS DRILLED

The rocks drilled are principally diabase, sulphide ore, and some sediments. Because these vary from hard to soft, there is a variety of drilling conditions, although there is no sticky drilling. The siliceous, massive sulphides are especially abrasive.

OPERATING PRACTICE

The diameters of the cylinders of the machine drills at present in use are as follows: Drifters, 3 and 3-1/2 inches; hand-rotated stopers, 2-3/4 inches; jackhammers, 2-1/2 and 2-5/8 inches. Drifters have a 30-inch run; stopers, 13 inch; and jackhammers, 24 to 28 inch. There is one man per machine, except for drifters in large headings, where there is a miner and a helper. The air pressure at the drill is about 80 pounds per square inch.

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The following sections of drill steel are in service: For drifters, 1-1/4-inch hollow lugged round; for stopers, 1-inch hollow quarter-octagon with plain shanks; and for jackhammers, both 7/8-inch hollow, collared, hexagon and 1-inch hollow, collared, quarter-octagon. All steel contains 0.95 percent carbon.

The steel-sharpening shop is in the mine yard near the portal of the supply adit. The equipment consists of the following: 2 machine sharpeners with punches, 2 single-opening oil-burning furnaces, 1 air hammer, 1 bolt machine, 1 drill press, 1 single emery wheel, 1 double emery wheel, 1 forge, 3 anvils, 1 bench vise, and 2 quenching tanks.

On the regular steel the conventional bits have an angle of 90° between the cutting faces and double clearance tapers of 5° and 14°. The gage of the starters is 2-3/16 inches and of finishers is 1-11/16 inches. Jackhammer starters less than 4 feet in length have a gage of 1-13/16 inches. The gage change is 1/8 inch.

With conventional bits on regular steel, the feet drilled per machine shift in raises is 68, and in shafts, 72. Using regular steel with jackhammers and stopers, the feet drilled per bit dulled in shafts, raises, and stopes varies from 2-1/2 to 16 and averages 6.53. The average depth of hole drilled is 5 to 6 feet. The estimated feet of hole drilled per month is 80,000. The loss of steel from all causes is 0.24 pound per bit sharpened, or 0.036 pound per foot of hole drilled.

Conventional bits are forged at an estimated temperature of 1,900° to 2,000° F. Three heats are generally required for fabricating new bits and one heat for resharpening them. For hardening, the bits are heated to a cherry red, or about 1,400° F., and are quenched in water to which some potassium cyanide has been added. The quenching tank is emptied and cleaned once each three months. Approximately 600 pieces of steel per day are sharpened and hardened by a crew of four men.

In forging shanks, two heats at a temperature of 1,900° to 2,000° F. are generally required. The steel is allowed to cool in air. On the following day the steel is normalized by heating slowly to about 1,400° F. After one hour at this temperature, it is set in a rack to cool in air. The shanks are hardened by heating the ends to 1,400° F. through a distance of 1 inch and by quenching in oil until cold. They are then placed in a rack to drain.

The steel is transported in cars, which are pushed on and off the cage at the shaft and are run throughout the various levels as required. Air hoists are installed at raises for handling the steel, which is loaded in wooden buckets 14 inches square and 24 inches high.

The following tabulation, based on estimated footages, shows the average cost per bit dulled and the average cost per foot drilled in stopes, raises, and shafts in connection with stopers and jackhammers using regular steel with conventional bits:

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Operating costs for drilling in stopes, raises, and shafts with conventional steel[1/]

	Cost per bit dulled	Cost per foot drilled	Accumulative cost per foot drilled
Reconditioning drill steel, total	$0.0839	$0.0129	$0.0129
Labor	.0428		
Steel replacement	.0411		
General shop expense, total	.0201	.0031	.0160
Compressed air	.0127		
Fuel oil and gas	.0030		
Supplies	.0044		
Transportation of drill steel, total	.1461	.0223	.0383
Through haulage adit	.0020		
Underground distribution and collection	.0198		
Hoisting	.0374		
Miners, toplanders, and raise hoistmen	.0869		
Operating machine drills	1.2965	.1985	.2368
Labor	.9042		
Compressed air	.1492		
Machine drill repairs	.1438		
Air lines	.0520		
Water lines	.0473		
Total operating exclusive of supervision	1.5466	.2368	.2368

1/ Based on studies made by Paul T. Allsman, assistant mining engineer, United States Bureau of Mines, in June 1936.

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DETACHABLE BITS

Detachable bits are used exclusively in driving drifts. Because large mounted machines are employed on this work and because all other drilling throughout the mine is done with smaller machines using regular steel and conventional bits, there is no common basis for a detailed comparison of results from the two systems. The estimated feet drilled per month with detachable bits is 13,000.

Since acquiring the original stock of detachable bits, all new bits purchased have been 2-1/4-inch gage. Detachable bits are not reground at the mine but are sent to a custom machine shop some 60 miles distant. A flat rate of 10 cents per bit is charged for sharpening. Bits are not ground to a definite gage but are first sharpened and then sorted into lots that have following gages with a maximum differential of 1/8 inch.

There is an average of 1.38 regrinds or 2.38 uses per bit purchased. The average feet drilled per bit dulled is 14.84, and the feet drilled per bit purchased is 35.3. The gage loss is 1/32 to 1/8 inch per bit dulled.

Rods are reconditioned at the company shops. Shanks are forged by exactly the same methods as employed for regular steel. The thread end is upset at the drill-sharpening shop and annealed in lime. The shoulder is turned and threads are rough cut on a lathe. The threads are then finished on hand dies. Hardening is accomplished by heating the entire length of the threaded portion to a slightly lower temperature than for hardening shanks, and by quenching in oil until cold.

The distance drilled per rod broken, based on a record of six rods, averaged 328 feet. On the basis of the number of times used, the breakage of the rods was 0.77 percent.

Bit carriers are simple loops of wire onto which the bits are strung. Bits are exchanged by the miners at the warehouse on the surface. The loss of bits from all causes for a recent 6-month period was 1.7 percent.

An interesting experiment for adapting detachable bits to hand-rotated stopers is now in progress. By making a ratchet an integral part of the front head on the stoper, rotation of the drill steel is confined to one direction. While the device seems to have possibilities for this particular field, yet it is still in the development stage and its operation has not been sufficiently extensive to permit forming final conclusions.

The following tabulation, based on estimated footages, shows the operating costs for drilling in drifts with a drifter having a cylinder 3-1/2 inches in diameter and using detachable bits.

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Operating costs for drilling in drifts with detachable bits[1/]

	Cost per bit dulled	Cost per foot drilled	Accumulative cost per foot drilled
Bits, total	$0.1727	$0.0116	$0.0116
New bits (at 27.3¢ each) 2.38 uses	.1147		
Regrinding bits (outside contract at 10¢ each)	.0580		
Rods, total	.0158	.0011	.0127
Labor, fabricating and reconditioning	.0070		
Steel replacement	.0088		
General shop expense (compressed air, fuel oil, gas, supplies), total	.0016	.0001	.0128
Transportation of rods, total	.0026	.0002	.0130
Through haulage adit	.0001		
Underground distribution	.0009		
Hoisting	.0016		
Operating machine drills, total	1.7454	.1176	.1306
Labor	1.3120		
Compressed air	.1648		
Machine drill repairs	.1589		
Air lines	.0574		
Water lines	.0523		
Total operating, exclusive of supervision	1.9381	.1306	.1306

1/ Based on studies made by Paul T. Allsman, assistant mining engineer, United States Bureau of Mines, in June 1936.

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THE HILLSIDE MINE, HILLSIDE MINES, INC., HILLSIDE, ARIZONA

CONCLUSIONS

Since detachable bits are used exclusively no operating statistics are available for comparison with statistics on conventional bits on regular drill steel. One of the advantages of the detachable bit at this mine is the small cost of nipping, while another is the elimination of all forging and hardening of bits and shanks at the mine shop.

ROCKS DRILLED

The principal rocks drilled are schist with quartz lenses and ore. These are seamy and may be either soft or hard and abrasive.

OPERATING PRACTICE

Two kinds of rock drills are used, viz, jackhammers with 3-1/2-inch diameter, which are also mounted for use as drifters; and 2-5/8-inch-diameter stopers equipped with automatic rotation. The hammer in each machine strikes the shank of the drill steel direct, without any intervening anvil block. There is one man per drill, except in very hard ground, where the operator has a helper. The air pressure is 90 pounds per square inch at the compressor.

All drilling is done with detachable bits. Sixty to eighty feet are drilled per machine shift. Drill holes average 5 feet deep. The footage per bit dulled is 15 to 20 feet.

The drill-sharpening shop is located at the portal of the adit. The equipment consists of one bit-grinding machine of standard make, a blacksmith's forge, and anvil. The sections of steel in use are hexagon, quarter-octagon, and round, all of which are 1-inch in diameter. The shanks on each section are lugged, so that there is in reality one universal class of drill steel at this property.

The life of rods was reported as satisfactory. When a shipment of broken rods has accumulated they are transported by truck and rail to a custom conversion shop 77 miles distant.

Bits are the standard four-point design with an angle of 90° between cutting faces. The blacksmith grinds the bits as a part of his routine when not engaged on other work. Miners exchange bits at the shop. New bits purchased are either 2 inches or 1-3/4 inches in diameter. They have two regrinds, or three uses. The life of a bit is 45 to 60 feet. Bits are discarded at 1-1/2-inch gage.

Bits are not rehardened. The length of run is 1 foot for hard ground and 2 feet for soft ground.

WESTERN MINE NO. 3

CONCLUSIONS

The use of detachable bits has been limited to long-hole drilling with Leyner steel in open-pit operations. This is because the economy in the use of detachable bits is largely due to the cost of steel transportation and nipping,

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which are at the maximum for regular steel when drilling long holes. The drilling speed of detachable bits exceeds that of conventional bits by 17.5 percent. In hard ground, on account of excessive abrasion in drilling which limits resharpening to one regrind, it has been found profitable at this mine to reforge and reharden detachable bits after each use.

ROCKS DRILLED

The principal rocks drilled are schist, porphyry, diorite, siliceous sulphide, massive sulphides, and sulphide ore. These present a wide range of drilling conditions, because they may be hard, abrasive, fitchery, shattered, seamy, or soft.

OPERATING PRACTICE

At this mine the sizes of the machine drills are as follows: jackhammers, 2-1/2 inches; sinkers and drifters, 3-1/2 inches; stopers, 3 inches; and wagon drills, 3-1/2 inches. There is one operator per drill for jackhammers and sinkers, while for the drifters and wagon drills there is an operator and a helper. With mounted drills in underground mining the miner is given help only when setting up his machine. The air pressure is 100 pounds at the compressor and about 85 pounds at the drill. With conventional bits on regular drill steel, the footage drilled per machine shift with wagon drills is 50 feet when drilling 20-foot holes. All drilling is wet.

The steel-sharpening shop is near the portal of the supply adit. A special truck with a horizontal box divided into four compartments is provided for transporting drill steel underground. For delivery on the surface, both track busses and auto trucks are used. All steel is segregated at the shop according to its length. The steel in service is 1-1/4-inch hollow, lugged round for drifters and wagon drills; 1-inch hollow, quarter-octagon for stopers; 7/8-inch hollow, collared hexagon for jackhammers; and 7/8-inch hollow, collared, quarter-octagon for pluggers.

The shop equipment is as follows: 1 shanking machine; 8 machine-sharpeners, including 2 spares; 8 punching machines; 13 oil furnaces using 1-1/4-pound air pressure; 11 pyrometers; 1 electric furnace; 2 automatic heat-treating machines; 2 circular, turntable-type, steel racks; 2 double emery wheels; and 1 detachable bit grinder. Machines are installed on each side of a central track. The floor areas adjacent to the side walls of the shop are laid with steel plates. This arrangement permits the use of trucks with flanged steel wheels. The oil quenching tank is water-jacketed on the sides by means of 160 feet of 1-1/4-inch pipe.

REGULAR STEEL

The full capacity of the shop is 2,500 pieces of regular drill steel per shift. One sharpener with a helper sharpens 375 to 400 Leyner bits per shift, or 450 to 500 jackhammer bits. About 100 pieces of steel per day are sharpened for each man in the shop.

For regular steel, the forging temperature as indicated by pyrometers on oil furnaces is 2000° F. The hardening heat is 1,425° to 1,430° F. Bits are quenched in cold water. The Brinell hardness of finished bits is 550 to 600.

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Shanks are forged and hardened as described below in the discussion on detachable bits.

For regular drill steel the gage change is 1/16 inch. The finishers for jackhammer steel have a 1-1/2-inch gage, while those for the mounted drills have a 1-9/16-inch gage. Jackhammers and mounted drills have a drill run of 15 inches.

Bits have a double taper of 5° and 14° with 90° between cutting faces.

Because of the large number of machine sharpeners in operation, it is possible to designate a separate machine for each bit size. By this means it is not necessary to change dies for different bit gages.

DETACHABLE BITS

Detachable bits are used only on Leyner steel for wagon drills and tripod drills on deep holes. Two men with a large drill average 57 feet of hole drilled per shift. From 500 to 700 bits are dulled per month.

Shanks are forged on rods at a temperature of 2,000° F. The hardening heat is 1,500° F. Quenching is done in a standard quenching oil. The Brinell hardness is 340 to 387. After upsetting at a temperature of 2,050° F. threads are cut on a lathe in the adjacent machine shop. For hardening, the thread end is reheated to 1,400° F. and quenched in oil until cold.

The maximum diameter of detachable bits used at this property is 3 inches. In drilling soft ground or rock that is not very abrasive, there are three regrinds or four uses per bit purchased. The distance drilled per bit purchased is 8.56 feet. Before badly worn bits are reground, they are annealed, and after regrinding they are rehardened. The life of a sharpening wheel with 12-inch diameter and 2-1/4-inch thickness averages 320 bits, while that of a gaging wheel with 12-inch diameter and 1-1/2-inch thickness is 900 bits. Bits are carried by the miners on a wire loop. A single jack, which has been partially annealed, and a Stillson wrench are used for loosening bits that are difficult to remove from the rod.

For use in hard, abrasive ground, where the first regrind would penetrate the hardened shell, the process of reforging detachable bits instead of regrinding them has been found preferable. By means of special dies for the machine sharpener, one bit per minute can be reforged. Three sets of dies are required for forging a complete set of bits with gage limits of 3 inches to 1-7/8 inches. For forging, the entire bit is heated evenly at 1,800° F. in an electric furnace with pyrometer attachment. A short piece of threaded steel rod is used to hold the heated bits in the machine sharpener. It has been found that for best results the rod should be cold when it is screwed into the heated bit. The bits are hardened in an automatic heat-treating machine with pyrometer attachment. They are heated to 1,430° or 1,500° F. and plunged into cold water to a depth of 1/2 inch for 10 seconds. The depth is then gradually increased until they are completely submerged.

COSTS

For conventional bits, the direct shop costs over a 5-month period for a total of 58,368 bits averaged 8.93 cents per bit sharpened. This was exclusive

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of the steel loss, which was estimated at 3 cents for Leyner steel. The cost for each class of regular steel is listed below:

Class of steel	Cost per bit sharpened, in cents
Underground steel, average	10.0
Open-pit steel, average	8.93
Plugger	6.6
Jackhammer	12.3
Leyner	15.7

The cost of transporting and nipping steel used in the open pit amounted to 6.61 cents per piece handled. The average shop cost is segregated as follows:

Item	Percent of total cost
Operating labor	69.02
Operating supplies	3.75
Fuel (Diesel oil)	7.28
Electric power	3.01
Compressed air	13.32
Repair labor	1.76
Repair supplies	1.86
Total	100.00

The relative cost of sharpening the several classes of regular steel is shown by the following ratios or sharpening cost factors:

Class of steel	Bit gage	Sharpening cost factor
Open pit:		
Plugger		1.00
Short jackhammer		1.64
Long jackhammer		2.25
Long Leyner	1-11/16 to 2-3/4	2.36
Underground:		
Leyner	1-9/16 to 1-11/16	1.55
	1-3/4 to 1-7/8	1.35
Stoper	1-1/2 to 1-7/8	1.50

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The following operating statistics compare the life of bit, rate of penetration, loss in bit gage, breakage of steel, and feet drilled per machine shift. They show that the detachable bit with 1-1/4-inch steel rod drills 12.1 percent farther and 17.5 percent faster, with smaller gage loss, than the conventional bit on regular steel.

Item	Regular steel, conventional bits	Detachable bits
Inches drilled per bit	21.99	25.66
Inches drilled per minute	9.49	11.15
Gage of bits used	2-3/4 to 1-5/8	2-3/4 to 1-9/16
Feet drilled for 1/32 inch reduction in gage:		
Quartz porphyry	4.84	5.10
Massive sulphides	1.28	1.69
Schist	1.19	1.72
Steel breakage (in percent of times used):		
7/8-inch plugger	.25	--
7/8-inch jackhammer	2.9	--
1-inch stoper	1.0	--
1-1/4-inch Leyner	2.0	--
Bit breakage, percent	1.4	2.1
Feet drilled per machine shift	50	57

At this property much of the advantage of the higher drilling speed of the detachable bit and its greater penetration per bit dulled have been counteracted by the increase in the number of broken bits and threads and by the additional difficulties in removing stuck bits. Of the total number of bits used, 4.8 percent required the use of a Stillson wrench to remove them from the rods. Under these circumstances, detachable bits are economical only in long-hole drilling in the open pit, where transportation and nipping costs for conventional bits are at the maximum rate for the mine, viz., 6.61 cents per piece of drill steel handled.

Because of the low cost of transporting and nipping regular steel, the use of detachable bits has not been considered for underground work.

BIG CANON MINE, MOUNTAIN COPPER CO., PLACERVILLE, CALIF.

CONCLUSIONS

At this mine detachable bits are economical only for special work, such as drilling in certain stopes where the transportation and nipping expense for regular steel is excessive. In comparing the detachable bits with the regular bits, the factor most favorable to the detachable bits is the outstanding saving in transportation and nipping. The factors unfavorable to the detachable bits

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are the reduction in drilling speed with the detachable bits, the excellent bit life for regular bits, and the small steel loss for regular bits.

ROCKS DRILLED

The prevailing formation is silicified schist in which the ore occurs as a replacement deposit accompanied by pyrite, quartz, ankerite, and calcite. Although the schist is universally dense, its hardness is variable.

OPERATING PRACTICE

Drifters having a diameter of 3-1/2 inches are used for all drilling except in raising. The common section of drill steel is 1-1/4-inch hollow round lugged for lengths under 10 feet. In soft ground, for lengths above 10 feet, 1-inch quarter-octagon is used. One man usually operates a machine, but where several machines are drilling in one face one helper may assist the entire group. Air pressure is 100 pounds at the compressor and about 90 pounds at the drill. The effective actual drilling time per 8-hour machine shift is 2-3/4 hours.

The drill-sharpening shop is near the collar of the main hoisting shaft. Equipment consists of 2 machine sharpeners, 2 punching machines, 1 pedestal shank-grinder, 1 bit-grinding machine, 1 double-opening oil-burning furnace using a 2-pound air pressure, 1 water quenching tank, 1 oil quenching tank, 1 forge and anvil, 1 air hammer, and various small tools.

CONVENTIONAL BITS

The miner or nipper selects his own drills at the underground steel racks. For hard rock the drill run is 14 inches and for soft rock it is 18 to 24 inches. Conventional bits are the 4-point end-hole type with 90° angle between cutting faces and with 5° and 14° clearance tapers. All drilling is wet. The 1-1/4-inch round steel carries a 5/16-inch hole. The gage change, starting with a 2-1/4-inch bit, is 1/8 inch per 12-inch run. For bits less than 1-7/8-inch gage the change is reduced to 1/16 inch per 12-inch run. The distance drilled per bit dulled is 1.17 feet.

Four men in the shop sharpen and harden an average of 700 pieces of regular steel per day.

DETACHABLE BITS

Detachable bits were adopted in February 1936 for use in certain stopes where the cost of transportation and nipping was very high for the regular steel.

With detachable bits, there is one operator for each machine and sometimes one helper for each three machines. Holes in stopes are drilled to a depth of 8 feet. Drifters average 41 feet per machine shift. A 3-pound annealed hammer is provided to facilitate the removal of bits that are not readily unscrewed. About 225 detachable bits are dulled per day. The distance drilled per bit dulled is 1.26 feet. Bits are the 4-point, end-hole type. The average number of bits broken is 0.28 percent of the total number used. The average feet drilled per rod broken is 76. Approximately one-eighth of total rod breakage is at the thread. Rods are 1-1/4 inches in diameter.

The drill run is 15 inches with 1/8-inch gage change. Bits are rehardened after the second regrind or third use, and thereafter on each regrind to a minimum size of 1-5/8 inches. Since the last three sizes are rehardened, the bits are

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annealed before regrinding. Since the rehardening practice was adopted there has been an increase in the number of regrinds to 4.8, which is equivalent to 5.8 uses per bit purchased. The life of a bit is 7.3 feet.

The grinding wheels are 12 inches in diameter. A forming wheel sharpens 500 bits and a gaging wheel gages an average of 300 bits. Approximately 180 bits are sharpened and gaged per man per shift on grinding.

Shanks on rods are forged at an estimated temperature of 1,800° to 1,900° F. They are quenched in a standard brand of quenching oil after having been heated to approximately 1,450° F. The thread end of the rod is turned on a lathe at the mine machine shop. It is then heated to an estimated 1,450° F. and sprinkled with a hardening powder. After a few seconds it is quenched in oil until cold.

The bit carrier is a loop of wire. The miner picks up sharp bits at the shop on the surface and delivers them at the close of the shift to the shaft station. A nipper returns them to the shop.

The following comparative costs show the results of a 3-weeks test made previous to the adoption of the detachable bits for special work. It does not include the loss of miners' time in handling steel nor the cost of operating machine drills.

	Conventional bits		Detachable bits		
	Cost per bit dulled	Cost per foot drilled	Unit cost	Cost per bit dulled[1/]	Cost per foot drilled
New bits	----	----	$0.27	$0.0530	$0.0420
Regrinding bits, total	----	----	.0611	.0491	.0390
Labor	----	----	.0346	----	----
Wheels	----	----	.0265	----	----
Reconditioning rods, total	----	----	----	.0048	.0038
Shanks	----	----	----	.0040	----
Threads	----	----	----	.0008	----
Steel loss	$0.0200	$0.0171	----	.0205	.0162
Sharpening	.0563	.0481	----	----	----
Fuel oil and miscellaneous shop supplies (estimated)	.0075	.0056	----	.0035	.0028
Nipping (estimated)	.0350	.0300	.035	.0100	.0080
Total	----	.1008	----	----	.1118

1/ Based on 5.1 uses per bit purchased.

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The operating data below show drilling speed, penetration per bit dulled, and loss of steel when drilling with conventional and with detachable bits:

Item	Conventional bits	Detachable bits
Drilling speed, inches per minute actual cutting time	4.4	4.0
Inches drilled per bit dulled	14.0	15.1
Breakage of rods, percent of times used	1.07	1.65
Loss of steel from all causes, pounds per bit dulled	.167	1/ .171

1/ Exclusive of steel in detachable bits.

WESTERN MINE NO. 4

CONCLUSIONS

By adopting detachable bits a saving of 45.7 percent is shown for bit-sharpening cost per foot drilled. Comparative drilling data indicate a considerable saving in complete costs. No small factor in the success of detachable bits at this property is the carefully controlled operations in the company's shops for reconditioning drill rods and bits.

ROCKS DRILLED

The prevailing formation is monzonite porphyry with some diorite and rhyolite. The rock varies from soft to very hard and from sticky through ravelly to dense and uniform. The average drilling is quite abrasive.

OPERATING PRACTICE

Since October 1, 1934, all drilling has been done with detachable bits. Vertical holes are drilled dry in an open pit to an average depth of 28 feet with 3-1/4-inch drills mounted on tripods and with 4-inch wagon drills. For plugging, a 2-5/8-inch machine is employed. Air pressure is 100 pounds at the compressor and 90 pounds at the drill. Over a recent 6-month period an average of 6.9 feet was drilled per bit dulled. The life of a bit is 48.3 feet.

The drill-sharpening shop is at the approach to the pit. The sections of drill-steel rods in use are 1-1/4-inch hollow lugged round, 1 inch-hollow lugged round, and 7/8-inch hollow collared hexagon. The steel carries about 0.9 percent carbon. Only 12-1/2 percent of the former drill-steel inventory is required for detachable bits.

The sharpening shop is 30 feet wide and 80 feet long. Its equipment comprises 2 grinding machines, 4 oil-burning furnaces using air at 14 pounds pressure, 1 electric furnace with pyrometer, 1 tempering furnace with oil bath and indicating pyrometer, 1 tempering furnace with salt bath and indicating

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pyrometer, 1 drill-rod-threading machine, 1 double emery wheel, 1 electrically driven hacksaw, 1 drill-steel-sharpening machine, together with anvils, quenching tanks, and small tools.

Detachable bits are the 4-point, end-hole type. New bits purchased have the following gages: 3-inch, 2-7/8-inch, and 2-3/4-inch. The gage change is 1/8 inch on a 4-foot run. The smallest bits used are 1-3/4 inch. Large holes are desirable to facilitate springing and loading. There are 6 regrinds or 7 uses per bit purchased. There is a loss in gage of 0.02 inch per foot of drilling. After the bits are sharpened, they are sorted to the nearest 1/8-inch gage. About 16,000 bits are used per month, or 620 per day. One man can grind and gage an average of 138 bits per shift. In the grinding process, bits are first sharpened on the forming wheel and then squared on the gaging wheel. Although no figures are available to show the actual percentage of bits lost, it is known to be almost negligible.

In grinding bits, two men work on each grinding machine. In one shift two men can form and gage 250 Leyner bits or 325 plugger bits. The life of forming wheels is 600 Leyner bits or 1,000 plugger bits, while for gaging wheels it is 700 Leyner bits or 1,100 plugger bits. One man can harden and temper 500 Leyner bits or 700 plugger bits.

Plugger bits, which are used for block-holing in the hardest rock, are rehardened after each use. Leyner bits used on 1-1/4-inch rods in mounted drills require rehardening after either the first or second regrind. An average day's classification of bits in service follows: New bits, 20 percent; bits reground only, 24 percent; bits rehardened and reground, 56 percent.

In the hardening process Leyner bits are heated for 50 minutes in the electric furnace at a temperature of 1,500° F. Plugger bits are heated for 45 minutes at a temperature of 1,450° F. Both kinds of bits are quenched in brine by placing the cutting edges on a punched plate shelf with 1/2-inch submergence in an open steel tank. A rising current of solution is maintained by means of a circulating pump in the tank. After 60 seconds the bits are removed from the shelf and completely submerged. After cooling, they are removed from the brine and reheated in the oil bath in the tempering furnace at a temperature of 400° F. The Leyner bits remain in the bath for 50 minutes and the plugger bits for 45 minutes. Upon cooling in the open air they are ready for use.

Detachable bits are transported in a steel tray divided into 12 compartments each 7-1/2 by 3 by 4-1/2 inches deep. Round iron handles project 3 inches across each end. The overall dimensions are 12 by 30 inches. The capacity of this tray is 60 bits. Drilling is continuous for 3 shifts per day. Bits are delivered in trays to the drill by a supply man. The drill operator replaces dulled bits in the tray, which is returned to the shop by a nipper.

RECONDITIONING RODS

Shanks are forged at 1,800° F. After the forging operation they are normalized by being heated to 1,500° F. and cooled in the open air. They are then given a hardening heat at 1,450° F. and are quenched in cool tempering oil.

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The ends of the shanks on the 1-1/4-inch steel are squared on the finishing dolly in the machine sharpener without grinding on an emery wheel. On the 7/8-inch steel, as the final shop operation, they are squared on an emery wheel.

The crew for shanking long drill rods consists of four men - one on the furnace, one on the sharpening machine, and two for handling the rods. This crew can forge shanks on 20 pieces of 1-1/4-inch lugged steel per hour, or 40 pieces of 7/8-inch collared steel per hour.

In the threading operation, the rods are first sawed off square and smooth. After being heated to 1,800° and upset in the sharpening machine, they are permitted to cool. They are then reheated to 1,400° F. and annealed in specially ground silica or in lime. After being reheated to an estimated 1,500° F. in an oil furnace, they are quenched in cool oil of standard grade for this work. They are tempered in a salt bath at 525° F. for 50 minutes. They are given an interrupted quench by being dipped briefly in water and cooled in air.

Previous to the adoption of detachable bits, a 10-day test was run in hard ground with two 3-1/4-inch drills mounted on tripods, during which the following data were developed.

Item	Conventional bits	Detachable bits
Total feet drilled	577.9	748.2
Drilling speed, inches per minute, actual cutting time	21.97	24.60
Feet drilled per bit dulled[1/]	2.30	3.33
Gages of bits, inches	2-3/8 to 2-1/2	2-7/8 to 3

1/ These figures recently increased to 5.24 for conventional and 6.90 for detachable bits.

Detachable bits thus showed a 12-percent increase in drilling speed and 44.8 percent increase in distance drilled per bit dulled.

Comparative partial costs per foot drilled for conventional and detachable bits are below. The costs for detachable bits are for a recent 6-month period, while the figures for conventional bits are for a similar period immediately preceding the adoption of detachable bits.

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Comparative partial costs of drilling

Item	Conventional bits		Detachable bits	
	Per bit dulled	Per foot drilled	Per bit dulled	Per foot drilled
Sharpening, total	$0.0996	1/ $0.0190	- - - -	- - - -
Labor	- - - -	.0130	- - - -	- - - -
Operating supplies	- - - -	.0038	- - - -	- - - -
Equipment repair supplies	- - - -	.0022	- - - -	- - - -
New bits, regrinding and rehardening; labor and supplies	- - - -	- - - -	$0.125	$0.0181
Rods, reconditioning:				
Threads: Labor, loss in steel, fuel; miscellaneous supplies; repairs to equipment	- - - -	- - - -	- - - -	.0006
Shanks	- - - -	- - - -	- - - -	2/
Steel loss, total	.0529	.0101	- - - -	- - - -
Sharpening loss	- - - -	.0029	- - - -	- - - -
Broken and stuck in hole	- - - -	.0072	- - - -	.0072
Transportation and nipping	.0996	.0190	- - - -	3/ .0007
Interest on steel inventory	- - - -	.0021	- - - -	.0003
Interest and depreciation on shop equipment; repairs and depreciation on shop building	- - - -	.0008	- - - -	.0008
Total	- - - -	.0510	- - - -	.0277

1/ Exclusive of compressed-air costs.
2/ Costs not segregated for this process during this particular period. Costs assumed to be the same for both classes of bits.
3/ Estimated.

WESTERN MINE NO. 5

CONCLUSIONS

Hot-milled conventional bits on regular steel are used for all routine drilling because the indicated cost per foot drilled is lower than with detachable bits.

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The following factors at this particular mine are favorable for conventional bits:

1. The sharpening shop has long been noted for fabricating conventional bits of a highly superior quality.

2. The sharpening costs for conventional bits are exceptionally low.

3. The distribution costs for conventional bits are well below the average for underground metal mines.

4. The cost for new detachable bits is excessive because of their short life as reflected in total feet drilled per bit. This is the result of drilling in extremely abrasive material, which rapidly destroys the bit.

5. The sharpening costs for detachable bits is higher than the average for metal mines.

6. The drilling speed is greater with hot-milled conventional bits.

7. The penetration per bit dulled is less with detachable bits.

The factors favorable for detachable bits are as follows:

1. Lower steel-replacement cost.

2. Low distribution cost.

3. Low interest and depreciation charges for sharpening-shop equipment and steel inventory.

4. Reduction in loss of miners' time account transporting steel (not shown in detailed costs).

ROCKS DRILLED

The rocks drilled comprise sedimentary and intrusive rocks, soft oxide ore, and siliceous massive sulphide ore. There are various phases of contact metamorphism and limestone replacement. These rocks vary from soft and sticky to hard and extremely abrasive.

OPERATING PRACTICE

All routine drilling at this mine is wet and is performed with conventional bits on regular steel. A unique feature of the sharpening process adopted in October 1934 is a combination of forging and hot-milling. The rock drill machines required for the wide range of drilling conditions are 3-1/4 to 4-inch drifters, 2-3/4- and 3-inch stopers, and 2-1/2- and 2-5/8-inch jackhammers. The air pressure at the compressor is 90 pounds and at the drills it is 77 to 85 pounds. The average depth of holes is approximately 6 feet. A sharp bit has an average penetration of 1.80 feet in dense, siliceous sulphides. The sections of steel in

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use are 1-inch, 1-1/8-inch, and 1-1/4-inch round for drifters; 1-inch and 1-1/8-inch round, hexagon, or quarter octagon for stopers; and 1- and 1-1/8-inch hexagon for jackhammers. The 1-1/4-inch steel for drifters is now obsolete and is not being replaced. The shanks on all these various sections are lugged round.

Bits have a 90° angle between cutting faces. Clearance tapers are 5° and 14°. The gage change for a 15-inch drill run is 1/8 inch for the larger bits and 1/16 inch for the smaller bits, as tabulated below:

Drill	Length		Bit gage		
	Feet	Inches	1-1/4-inch steel	1-1/8-inch steel	1-inch steel
Starter - - - - - -	2	6	2-1/16	2	1-7/8
Second - - - - - - -	3	9	1-15/16	1-7/8	1-3/4
Third - - - - - - -	5	0	1-13/16	1-3/4	1-5/8
Fourth - - - - - - -	6	3	1-3/4	1-5/8	1-9/16
Fifth - - - - - - -	7	6	1-11/16	1-9/16	1-1/2

A 24-inch drill run is being considered for drills with automatic feed.

The drill-sharpening shop is near the collar of the supply shaft. The equipment consists of 7 sharpening machines, including one spare; 7 pedestal punches; 6 furnaces, using gas at 12 pounds and air at 90 pounds pressure; 1 gas-fired lead bath with pyrometer; 4 hot millers; 1 large furnace for normalizing; 1 double emery wheel; 1 water quenching tank; 1 oil quenching tank with water jacket and circulating pump; and steel trucks with revolving racks with four compartments.

The estimated forging temperature for bits is 1,800° to 1,900° F. Bits are hot-milled on the same heat as for forging. The accuracy of gaging by this method is shown by the established tolerance, which is less than 1/64 inch for this process. The wear on the milling wheel is very small. The wheel now in service, which was made in the company's shops, has sharpened approximately 200,000 bits but exhibits comparatively no wear.

For hardening, bits are heated in a lead bath in a cast-steel pot. The temperature of the lead is maintained between 1,425° and 1,440° F. by means of an indicating pyrometer and manually controlled gas burner. It requires 1-1/2 hours to heat the lead to the proper temperature. The drill steel is placed in a circular steel turret, which moves in the lead pot at the rate of 30 revolutions per hour. The turret holds 16 pieces of steel. Since each piece of steel remains in the bath for one revolution, or 2 minutes, the capacity per hour is 480 pieces. The submergence of the bits in the lead is 7/8 inch. To prevent oxidation, the molten lead is covered with a layer of charcoal 1 inch to 1-1/4 inches deep. The weight of lead in the pot is 1,100 pounds. The replace-

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ment lead averages about 11 pounds per day.

Bits are quenched by complete submergence in a rising current of cold water.

Shanks are forged at 1,800° to 1,900° F. (estimated), reheated in a gas furnace to 1,500° or 1,550° F., and hardened by quenching in a standard oil for this purpose.

The entire drill steel in service is normalized at regular 18-month periods by heating in the normalizing furnace to 1,450° F. and cooling in the open air. Bits and shanks are then rehardened as described above. No figures are available to show the relative life of the normalized drill steel as compared with the non-normalized.

An average of 1,800 pieces of steel are sharpened per day. This requires a crew of eight men on sharpening and two on hardening. In addition, there is one supervisor. The output per sharpening machine per shift is 450 bits. This high rate is possible on account of finishing the bits on the hot-milling machines.

There are two types of special cars for transporting drill steel in service, one of which can be suspended in the cage for hoisting or lowering through the shaft.

COMPARISON OF HOT-MILLED BITS WITH FORGED BITS

The principal advantage of the combination forging and hot-milling over straight forging lies in the reduction in sharpening-shop expense. A disadvantage is the increased loss of steel. Labor is reduced 15 percent, or $0.0074 per bit sharpened, while the steel replacement is increased $0.0053. This makes a net advantage for hot-milling of $0.0021, or approximately 1/5 cent per bit sharpened. The comparative operating statistics shown below indicate a 7 percent increase in penetration for the hot-milled bit and approximately the same drilling speed.

Item	Forged bits	Hot-milled bits
Inches drilled	2,866	3,066
Inches drilled per minute	7.07	7.03
Inches drilled per bit dulled	20.18	21.59
Inches loss in gage per foot drilled	.074	.072
Average bit gage, inches	1-7/8	1-7/8
Steel loss, inches reduction in length of drill steel per bit sharpened:		
Wear in drilling	.07	.07
Sharpening	.26	.43
Total	.33	.50

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COMPARISON OF HOT-MILLED BITS ON REGULAR DRILL STEEL WITH DETACHABLE BITS

On a special test in dense siliceous sulphide with 1-1/4-inch drill steel and a 4-inch drifter equipped with automatic feed, the operating data shown below were developed. These results are favorable to the hot-milled conventional bit. They indicate that with the detachable bit there is a reduction in the penetration per bit of 16.5 percent and a decrease in drilling speed of 3.4 percent.4/

4/ In this test four different kinds of detachable bits were used. The figures in this comparison represent the detachable bit with the most favorable showing.

The detachable bits were used until either the clearance was lost or until the hardened steel shell was worn through. The number of bits that were reground after the first use was 70.8 percent of the bits purchased. Fourteen and three-tenths percent of the "first regrinds" were reground the second time. This totals 0.81 regrinds or 1.81 uses per bit purchased. The life of a detachable bit is 3.3 feet.

Item	Hot-milled bits on regular steel1/	Detachable bits
Inches drilled	3,066	2,085
Number of bits dulled	142	100
Inches drilled per minute	7.03	5.87
Inches drilled per bit dulled	21.59	20.85
Inches loss in gage per foot drilled	.072	.071
Average gage of bits, inches	1-7/8	1-31/32
Average air pressure, pounds/square inch	77.17	77.81

1/ These figures also used in comparison with straight forged bits above.

The cost of sharpening, reconditioning, and distributing, calculated on the per-foot-drilled basis and detailed below is 66.4 percent greater for detachables than for hot-milled conventional bits. The estimated total cost per foot drilled would show a greater differential than this because of the decreased penetration and reduction in drilling speed with the detachable bits.

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In the cost details, interest on the capital expense was computed at the annual rate of 4 percent and depreciation at 10 percent.

The construction cost of the drill-sharpening shop building was $5,000. For hot-milled conventional bits the purchase price of the shop equipment was $20,000 and the inventory value of the drill steel in circulation was $21,900.

For detachable bits, work would continue in the same $5,000 shop. The value of the shop equipment essential for detachable bits would be $7,500, and the inventory value of sufficient drill rods for all drilling throughout the mine would be $1,800.

Sharpening Shop and Distribution Costs

Item	Hot-milled conventional bits on regular steel[1]		Detachable bits[4]		
	Per bit dulled[2]	Per foot drilled[3]	Per unit	Per bit dulled	Per foot drilled[5]
New bits	----	----	$0.23	$0.1271	$0.0730
Sharpening, total	$0.0497	$0.0276	.0700	.0313	.0180
Labor	.0420	----	.0625	----	----
Supplies	[6].0077	----	[7].0075	----	----
Shanking	.0006	.0003	----	----	----
Reconditioning rods, total	----	----	----	.0015	.0009
Shanks	----	----	----	.0006	----
Threads	----	----	----	.0009	----
Steel replacement	.0208	.0116	----	.0036	.0020
Distribution, total	.0247	.0137	----	[8].0066	.0038
Underground nipping	.0191	----	----	----	----
Hoisting and surface handling	.0056	----	----	----	----
Interest on capital expense, Steel shop, equipment, and steel inventory	.0060	.0033	----	.0017	.0010
Depreciation, steel shop and equipment	.0072	.0040	----	.0035	.0020
Grand total	.1090	.0605	----	.1753	.1007

1/ Over a recent 12-month period.
2/ 346,741 pieces of steel sharpened.
3/ 1.80 feet drilled per bit dulled.
4/ Special test (see discussion and data above).
5/ 1.74 feet drilled per bit dulled.
6/ Includes fuel (gas), compressed air, dies, dollies and miscellaneous supplies.
7/ Includes grinding wheels and electric power.
8/ [illegible]

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ANACONDA COPPER MINING CO., BUTTE, MONT.

The Anaconda Copper Mining Co. was one of the first of the large mining companies to adopt the detachable bit. A complete description of the use of these bits at Butte may be found in an article by C. L. Berrien in volume 91 (1930) of the Transactions of the American Institute of Mining and Metallurgical Engineers.

The advantages of the detachable bit at this property in comparison with regular steel are stated in this article to be, (1) a reduction of 35.4 percent in the cost per cubic foot excavated, (2) a saving of several hours per day at each mine in transporting drill steel through the shaft, (3) an adequate drill steel supply, and (4) greater ease and less hazard in transportation of drill steel.

USE OF DETACHABLE BITS AT SMALL MINES, COMPARED TO LARGE MINES.

Figures that show the relative use of detachable bits by small and by large metal mines were furnished by a detachable-bit distributor who dominates this particular field in one Western State. These indicate that 92.3 percent of the users of detachable bits in this State are small operators, while 7.7 percent of the users are large operators. The small mines accounted for 33 percent of consumption and the large mines for 67 percent.

DISCUSSION OF LIFE OF DRILL RODS

One of the vital factors in connection with the use of detachable bits is the life of the drill rods. The question is often raised whether drill rods for detachable bits will deliver the same ultimate service in feet of hole drilled as will regular drill steel. The basis of this inquiry is the relative fatigue of steel that is used continuously and of steel that has short periods of use with long periods of rest.

> "The generally accepted idea of the mechanism of fatigue failure is that of the progressive spread of a minute crack, or of a plane of cleavage, from some nucleus. The nucleus may be a minute region of high localized stress (the root of a screw thread, for example), or a minute flaw or region of weakness in the structure of the metal."5/

5/ Moore, H. F., Kommers, J. B., and Jasper, T. M., Fatigue or Progressive Failure of Metals Under Repeated Stress: American Society for Testing Metals, vol. 22, part 2, 1922.

> "Results of experiments show that the fatigue strength of iron and steel is greatly influenced by heat treatment. Overheated steel is always weak, but can often be restored by reheating. Annealing in general decreases the endurance. Steel in the sorbitic condition seems to be especially strong

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against fatigue. It is certain, however, that the effect of heat treatment must always depend greatly upon the previous history of the material. From the few data that are available, it would seem that when metal has been subjected to repeated stresses it cannot be restored by annealing or by rest. The results are probably due to the fact that the metal had been so highly stressed or the number of repetitions so large that slip bands or actual microscopic fissures had been formed which were not healed by annealing.6/

6/ Fatigue of Metals: Johnson's Materials of Construction, 6th ed. 1926, chap. XXVIII, p. 825.

Metallurgists now agree that rest periods for drill rods have no benefit except in the psychological effect on the user, and that minute cracks once started can not be healed. Because of this characteristic, rough handling of drill steel and drill rods, or any abuse in the shops, in transit, or in use that causes a nick or mark on the finished surface of the drill steel is detrimental. Many mines have increased the life of drill steel and rods appreciably by careful handling.

LIFE OF DRILL RODS AT MIAMI COPPER CO., MIAMI, ARIZ.

The Miami Copper Co. has developed some very interesting data on the life of drill rods for detachable bits. The following tabulations, furnished by R. W. Hughes, mine superintendent, are especially complete. Table 1 shows the comparative life of rods fabricated from new bars, from broken bars that were reforged after the first and second failures, and from old drill steel of indeterminate service. This table indicates that new steel in its first service has the longest life; that, of the three classes under consideration, stoper rods render the greatest service and drifter rods the least; and that rods converted from old drill steel have only one-fifth the life of new steel in its first service.

Table 2 classifies drill-rod failures according to their location with respect to the shank, the thread, or some position intermediate between the two ends. This table shows that most failures occur in the midsection rather than at the ends and that failures in the threads are negligible.

Table 3 segregates the failures by the length of the rods. It reveals that seconds have the highest breakage frequency and that drifter seconds exhibit the greatest rate of the three types.

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TABLE 1. - LIFE OF DRILL RODS

Section	New steel						Old steel from used drills		All Steel	
	1st service		2d service		3d service		1st service			
	Pieces	Days life	Pieces	Days life	Pieces	Days life	Pieces	Days life	Pieces	Days life
Drifter 1-1/4-inch round - - - - -	81	35	21	16	2	28	19	10	123	28
Stoper 7/8-inch quarter octagon	21	93	10	32	1	19	0	0	32	71
Plugger 7/8-inch hexagon - - - -	32	58	7	30	0	0	2	8	41	51
All steel - - - -	134	49	38	23	3	23	21	10	196	40

TABLE 2. - DRILL-ROD FAILURES, CLASSIFIED ACCORDING TO LOCATION OF BREAK.

Section	New steel						Old steel from used drills			Total
	1st service			2d and 3d services			1st reservice			
	Shank	Between shank and thread	Thread	Shank	Between shank and thread	Thread	Shank	Between shank and thread	Thread	
Drifter, 1-1/4-inch round - - -	43	40	6	8	13	4	12	7	0	133
Stoper, 7/8-inch quarter octagon - -	3	26	0	0	11	0	0	0	0	40
Plugger, 7/8-inch hexagon - -	9	21	0	3	9	0	2	0	0	44
Total - -	55	87	6	11	33	4	14	7	0	217
Percent -	37	59	4	23	69	8	67	33	0	- - -

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TABLE 3. - DRILL-ROD FAILURES SEGREGATED BY LENGTH OF RODS

Class	Drifter failures	Length of rod inches	Percent	Stoper failures	Length of rod inches	Percent	Plugger failures	Length of rod inches	Percent	Total failures	Percent
Starter -	24	30	16	7	30	15	9	24	17	40	16
(2d) - -	99	58	66	20	48	43	30	48	58	149	60
(3d) - -	26	86	17	15	66	32	12	72	23	53	21
(4th) - -	1	114	1	4	84	9	1	96	2	6	2
(5th) - -	-	-	-	1	102	1	-	-	-	1	1
Total	150	-	100	47	-	100	52	-	100	249	100

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APPENDIX I

Mine	Rock drilled	Feet drilled per rod broken		Total life detachable bit, feet drilled
		Conventional	Detachable	
Geneva	Granite	---	---	---
Soudan	Greenstone, jasper, and iron ore	---	---	15.6
Greenwood	Jasper and hard iron ore	---	120	8.6
Bates	Hard limonite	---	---	5.5
Montreal	Quartz slates	---	---	---
Vulcan	Medium hard ore, slate, and cherty iron formation	---	---	---
Calumet & Hecla	Copper ore	---	---	---
Champion	Amygdaloid	---	---	8 to 16
Homestake	Siliceous ore	---	---	---
Cliffs shaft	Hard hematite ore	---	---	6.0
Mascot	Dolomite and limestone	---	166	43.8
Bendelari	Limestone and flint	159	432	6.9
Barr	Flint and tiff	142	---	4.0
Rialto	Limestone and flint	---	2,1334	9.6
A mine in S.E. Missouri	Dolomitic limestone	11,340	---	---
Burra Burra	Metamorphosed sediments	320	---	---
London	Limestone, quartzite, porphyry, and vein matter	---	---	13.0
Climax	Silicified granite and schist	---	320	28.8
Utah Apex	Limestone, quartzite, porphyry, and sulphide ore	---	932	25.0
Idaho-Maryland	Schist, serpentine, diabase, diorite, quartz	---	---	17.2
Western Mine No. 1	Metamorphosed sediments diabase and porphyry	---	341	44.6
United Verde Extension	Gossan, diorite, schist, greenstone and porphyry	---	200[1/]	10[1/]
Western Mine No. 2	Sulphide ore, diabase and sediments	---	328	35.3
Hillside	Schist with quartz lenses and ore	---	---	45 to 60
Western Mine No. 3	Schist, porphyry, diorite, sulphides, and ore	92	---	8.6
Big Canon	Silicified schist	109	76	7.3
Western Mine No. 4	Monzonite porphyry, diorite, and rhyolite	---	---	48.3
Western Mine No. 5	Metamorphosed sediments, porphyry, and sulphide ore	---	---	3.3

1/ Approximate.

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APPENDIX II

Mine	Diameter machine drill (maximum)	Bit gages		Drilling speed inches per minute	
		Conventional	Detachable	Conventional	Detachable
Geneva - - - -	4	2-3/8 - 1-3/4	2 - 1-5/8	3.81	6.11
Soudan - - - -	{3-1/2 / 3}	2-1/8 - 1-5/8	2 - 1-5/8	0.33 to 1.90	0.42 to 2.09
Greenwood - -	3	2-5/8 - 1-5/8	2 - 1-1/2	3.46	4.75
Bates - - - -	3-1/2	- - - - - - - -	- - - - - - - -	8.74	10.90
Montreal - - -	4	2-5/8 - 1-1/2	2-1/4 - 1-3/4	8.1	10.6
Vulcan - - - -	3-1/2	- - - - - - - -	- - - - - - - -	- - - - -	- - - - - -
Calumet & Hecla - - -	-	1-5/8 - 1-3/8	1-3/4 - 1-5/8	8.2	8.8
Champion - - -	-	1-7/16 - 1-1/4	1-7/8 - 1-9/16	10.0	9.9
Homestake - -	3-1/2	2-1/2 - 1-1/2	- - - - - - - -	12.0	12.0
Cliffs Shaft -	3-1/2	2-9/16 - 1-5/8	1/ 2	1.77	2.90
Mascot - - - -	3-1/2	2-1/4 - 1-3/4	2 - 1-1/2	2/ 6.0	7.0
Bendelari - -	3-1/2	2-7/8 - 1-3/4	2-7/8 - 2-1/4	13	13
Barr - - - - -	3-1/2	2-5/8 - 2-1/8	2-1/2 - 2-1/8	-	-
Rialto - - - -	4	2-3/4 - 1-5/8	2-1/2 - 2	-	-
A mine in S.E. Missouri - -	2-3/8	1-3/8 - 1-1/16	-	12	-
Burra Burra	4	1-7/8 - 1-3/8	2-3/4 - 1-3/4	-	-
London - - - -	3-1/2	-	2 - 1-3/4	-	-
Climax - - - -	4	-	2-7/8 - 1/ 2	-	18
Utah Apex - -	3	2-1/8 - 1-7/8	2-1/8 - 1-3/4	2.15	2.51
Idaho-Maryland	3-1/2	-	1/ 2-3/8	-	-
Western Mine No. 1 - - -	3-1/2	-	2-1/8 - 1-1/2	-	6 to 15
United Verde Extension -	3-1/4	- - - - - - - -	- - - - - - - -	- - - -	- - - - - -
Western Mine No. 2 - - -	3-1/2	2-3/16 - 1-11/16	1/ 2-1/4	-	-
Hillside - - -	3-1/2	-	2 - 1-1/2	-	-
Western Mine No. 3 - - -	3-1/2	2-3/4 - 1-1/2	3 - 1-7/8	9.49	11.15
Big Canon - -	3-1/2	2-1/4 - 1-5/8	2-1/4 - 1-5/8	4.4	4.0
Western Mine No. 4 - - -	4	2-1/2 - 2-3/8	3 - 1-3/4	21.97	24.60
Western Mine No. 5 - - -	4	2-1/16 - 1-1/2	1/ 2	7.03	5.87

1/ Starters only.
2/ Approximate.

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APPENDIX III

Mine	Cost per foot drilled			
	Conventional bits			Total detachable bits
	Transportation of steel	Nipping by miners	Total	
Geneva	-	-	-	-
Soudan	-	-	-	-
Greenwood	-	-	$0.183	$0.105
Bates	-	-	-	-
Montreal	-	-	-	-
Vulcan	-	-	-	-
Calumet & Hecla	-	-	.028	-
Champion	-	-	-	-
Homestake	-	-	-	-
Cliffs Shaft	-	-	-	-
Mascot	$0.0026	-	.0928	.0829
Bendelari	-	-	-	-
Barr	-	-	-	-
Rialto	-	-	-	-
A mine in S.E. Missouri	-	-	-	-
Burra Burra	-	-	-	-
London	-	-	-	2/.1975
Climax	.0198	.0193	2/.043	3/.026
Utah Apex	.0578	-	3/.1093	3/.0170
Idaho-Maryland	.0170	-	.0607	.0399
Western Mine No. 1	.0209	-	4/.0466	5/.0060
United Verde Extension	-	-	-	-
Western Mine No. 2	.0223	.0223	6/.2368	7/.1306
Hillside	-	-	-	-
Western Mine No. 3	-	-	-	-
Big Canon	8/.0300	-	.1008	9/.1118
Western Mine No. 4	.0190	-	3/.0510	3/.0277
Western Mine No. 5	.0137	-	3/.0605	3/.1007

1/ The above costs do not include drilling labor and compressed air.
2/ Includes operating rock drills.
3/ Cost of steel and bits, shop expense and transportation.
4/ Shop and transportation only.
5/ Shop costs only (exclusive of cost of new bits).
6/ In stopes, raises and shafts.
7/ In drifts
8/ Approximate
9/ Detachable bits used in special work where transportation cost is higher than average shown.

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